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Effect of upstream fencing on shelter zone behind solid models simulating sand formations and dunes

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KEYWORDS

Sand;
Dune;
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Abstract This paper presents and discusses flow patterns around solid models constructed to represent sand (or snow) formations and dunes with and without upstream fencing. These flow patterns were obtained experimentally (by visualization) as well as computationally. The objective here is to give recommendations regarding protection against dangers posed by drift and/or movement of dunes on nearby roads and structures. The effects of mounting upwind fences on the flow pattern and the location of reattachment relative to dune base (shelter zone length) were examined. The effect of fencing was graphically plotted with fence position and height for given dune form. Computation and experiment showed acceptable agreement.

Moreover, results indicate that some dune/fence combinations may cause shifting of the dune upwind (instead of downwind in the absence of fence). This effect means that, with such combinations, a dune would eventually disappear. The distance between the model downwind base line and the location of reattachment (length of shelter zone) was plotted against the distance of fence from upwind base line of model to determine the best possible dune/fence combination. Solid fencing (constructed from masonry bricks or stones) to shelter isolated sand humps and dunes is effective in alleviating dangers on nearby structures (dune shifting upwind and to less sand drift and saltation downwind). Also, the results indicated that, it is recommended to start by dune fencing and give enough time for the project zone to widen and be effectively protected before starting the construction.

Introduction

The problem of sand drift and dune formation and movement bears vital importance in countries where deserts constitute large portions of the land. In countries with heavy snowfall, the problem is also important. Such importance stems from the fact that roads, highways and other installations are highly jeopardized by sand (or snow) drift and dune movement, unless some means to limit this effect are applied. Desertification of cultivated land is another obvious danger. It is therefore

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vitally important to search for and devise viable means of controlling the formation of dunes or at least stopping or limiting their movement (the so called dune stabilization).

Several studies have been carried out on the problem and may be categorized as: field studies [1], Sauermann [2], Wang [3], laboratory studies Bruce [4], Pascal [5], Shaalan [6–8], and analytical/numerical studies Alhajraaf [9], Tosar [10]. Various techniques Ibrahim [11], Price [12] have been adopted. Guirguis and Younis [13] present and discuss results of some experimental and computational work on flow around idealized models of sand humps and dunes found in nature using a smoke tunnel to obtain pictures of flow patterns around the models with and without fencing in an attempt to reach the best possible fence height and location. The computational work was carried out using a commercial software package "ANSYS" [14].

Chemical methods (such as asphalt and bitumen) and traditional methods (wind breaking, vegetation and laying bricks and stones on dune surfaces) have been applied with limited effectiveness in most cases. Also, such techniques are non-economical and require frequent maintenance. The problem may be looked upon scientifically by examining the flow pattern in the dune zone. Monitoring the flow pattern around the dune would certainly help devise an effective method of controlling its movement via adjustment and control of the flow pattern itself. Solid fencing is one method of controlling dune movement via study of the flow pattern.

Because of the difficulties encountered in carrying out field experiments on fencing of sand dunes, the problem is dealt with in the laboratory, either on sand-built scale model dunes Shaalan [9–11] or on solid models with roughened surfaces. With sand-built models, the problem of contamination of the surrounding environment by the exhausted air-borne sand arises. With solid models such problem is avoided. These solid models may be tested in a wind tunnel or in a smoke tunnel where the flow pattern is visualized with and without fencing. Examination of the flow patterns in this case is expected to lead to the best dune/fence combination that would minimize dune erosion rate and shifting downwind. In one case, this condition is verified with severely turbulent and circulatory flow created in the zone bounded by fence and dune. In other case the flow may be forced to be parallel to the windward surface of the dune. In the first case, the dune would eventually shift upwind and in the second case, saltation downstream is limited. Fig. 1 shows a schematic that illustrates these two cases.

In the present work, the flow around several idealized scale models representing dunes was visualized with and without upstream fencing. Also, the flow pictures obtained were supported computationally using the ANSYS FLOTRAN software package [2].

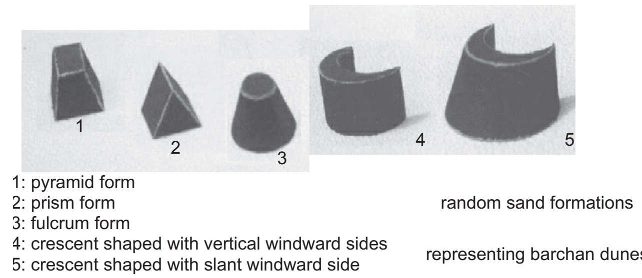

Fig. 2 Photo of tested models.

Models and test setup

Dunes are found in nature in various forms, depending on geography and wind prevailing wind regime. Also, random sand formations (hills) are frequently encountered in open deserts. For the purpose of the present work, five different models, idealizing isolated formations and dunes, were constructed from solid wood and with roughened surfaces. Three models were used to represent sand formations. Two crescent-shaped models were constructed to represent the well-known barchan-type dunes. These models are shown in Fig. 2. In the testing, each model was mounted on a roughened flat plate (representing the natural terrain of sand bed) and model fences of various lengths and heights were mounted upstream at various distances from the model. The model/fence/plate setup was then mounted inside the working section of a standard smoke tunnel.

Experimental work

For each model, several fence arrangements (height, length and inter-distance) were tested. The wind speed was adjusted until the smoke lines were clearly visible so that a sharp picture was obtainable. Geometrical details of the tested model and fence are shown on the corresponding result (Figs. 3–17).

Computation

Velocity distributions (contours and vectors) around models were obtained by application of the well-known ANSYS

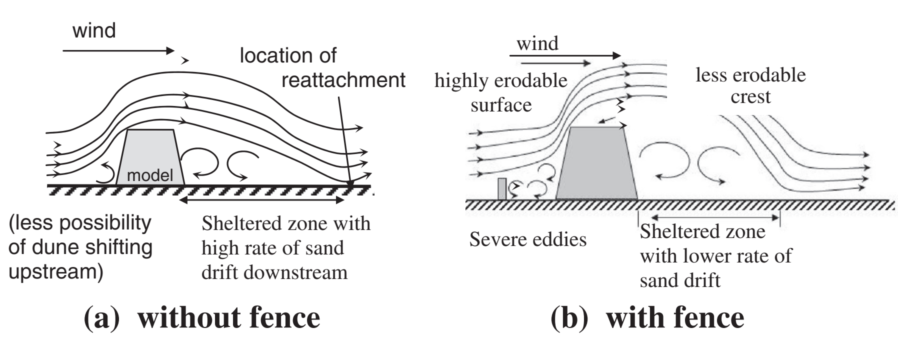

Fig. 1 Expected flow pattern around dune model.

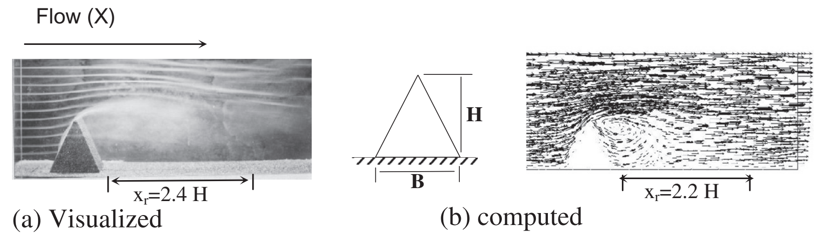

Fig. 3 Flow pattern around a square-based triangular prism model, (no fence, $H/B = 1$, $b/H = 0$).

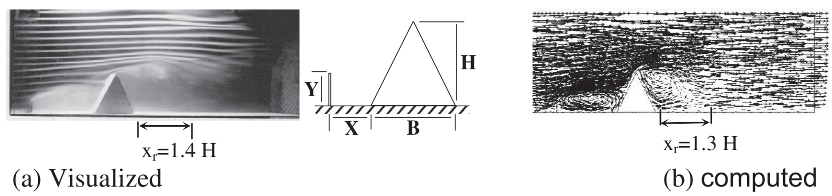

Fig. 4 Flow pattern around a square-based triangular prism model, (with fence: $H/B = 1$, $Y/H = 0.3$, $x/H = 1.5$, $b/H = 0$).

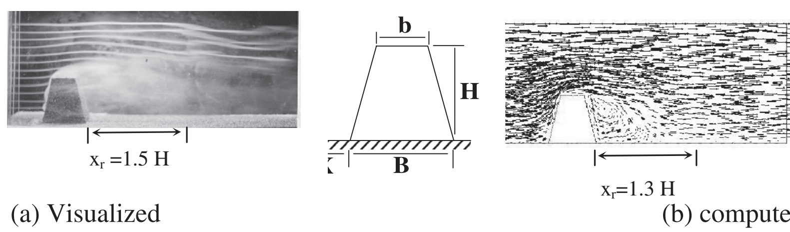

Fig. 5 Flow pattern around a square-based trapezoidal prismatic model, no fence: $H/B = 1$, $b/H = 0.5$).

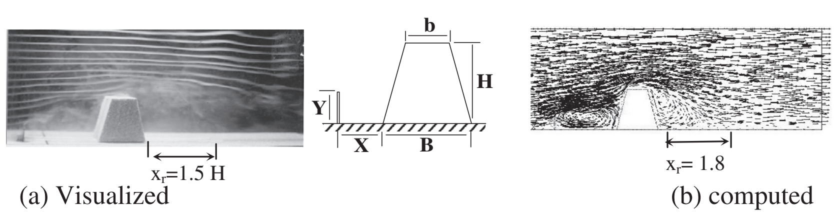

Fig. 6 Flow pattern around a square-based trapezoidal prism model, (with fence: $B/H = 1$, $b/H = 0.5$, $Y/H = 0.3$, $x/H = 1.5$, $b/H = 0$).

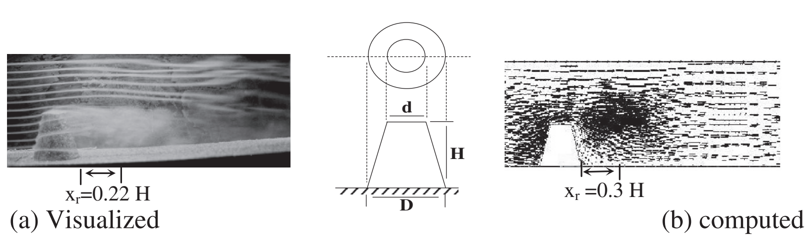

Fig. 7 Flow pattern around a fulcrumed-cone model, (no fence: $D/H = 1$, $d/H = 0.5$).

CFD code. The ANSYS CFD FLOTRAN version is a computer package [2] used for predicting the flow pattern (pressure and velocity vectors and contours) around arbitrary objects. The program is three-dimensional and utilizes the finite element approach, with the k–ε turbulence model and solves the Reynolds equations, the energy equation and the equations

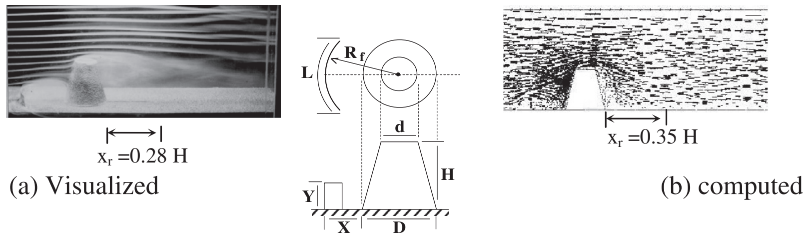

Fig. 8 Flow pattern around a fulcrumed-cone model, (with circular (R_f/D) fence: $D/H = 1$, $d/H = 0.5$, $Y/H = 0.3$, $L/D = 1.1$, $x/H = 1.0$).

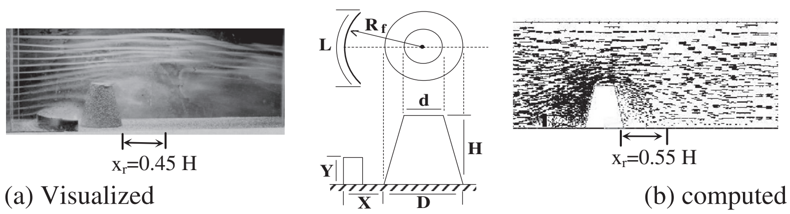

Fig. 9 Flow pattern around a fulcrumed-cone model, (with circular fence: $D/H = 1$, $d/H = 0.5$, $Y/H = 0.3$, $L/D = 3.1$, $x/H = 1.0$).

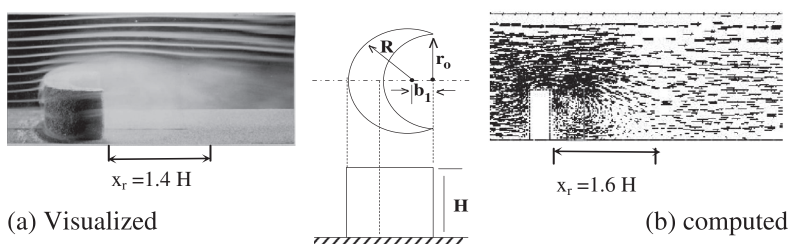

Fig. 10 Flow pattern around crescent-shaped model with vertical windward and leeward sides (idealized ‘‘Barchan’’ dune), (no fence: $H/B = 2.3$, $r_o/R = 0.9$, $b_1/b = 0.3$).

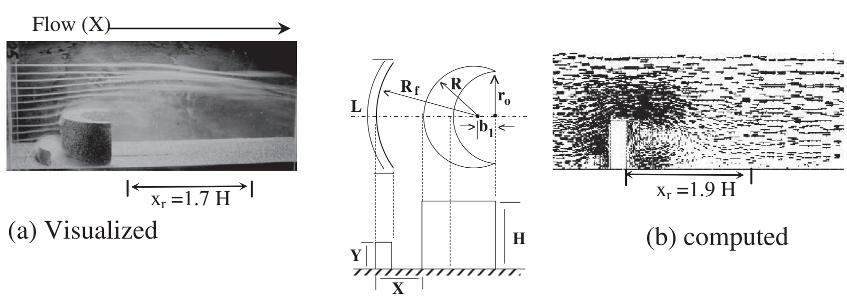

Fig. 11 Flow pattern around crescent-shaped model with vertical windward and leeward sides (idealized ‘‘Barchan’’ dune), (with circular fence: $H/B = 2.3$, $r_o/R = 0.9$, $b_1/b = 0.3$, $Y/H = 0.3$, $L/2R = 1.0$, $R_f/R = 1.4$, $x/H = 0.5$).

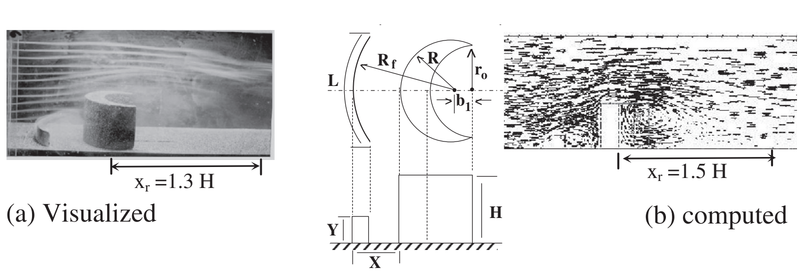

Fig. 12 Flow pattern around crescent-shaped model with vertical windward and leeward sides (idealized ‘‘Barchan’’ dune), (with circular fence: $H/B = 2.3$, $r_o/R = 0.9$, $b_1/b = 0.3$, $Y/H = 0.3$, $L/2R = 1.0$, $R_f/R = 1.4$, $x/H = 1.0$).

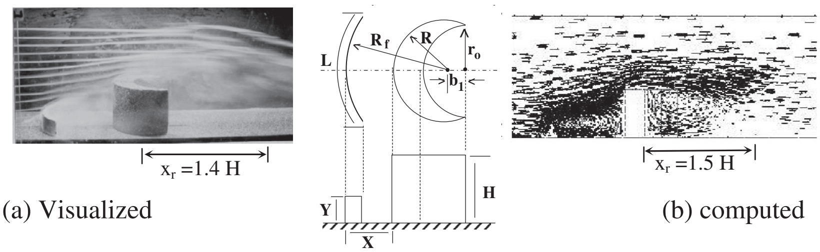

Fig. 13 Flow pattern around crescent-shaped model with vertical windward and leeward sides (idealized "Barchan" dune) (with circular fence: $H/B = 2.3$, $r_o/R = 0.9$, $b_1/b = 0.3$, $Y/H = 0.3$, $L/2R = 1.0$, $R_f/R = 1.4$, $x/H = 1.5$).

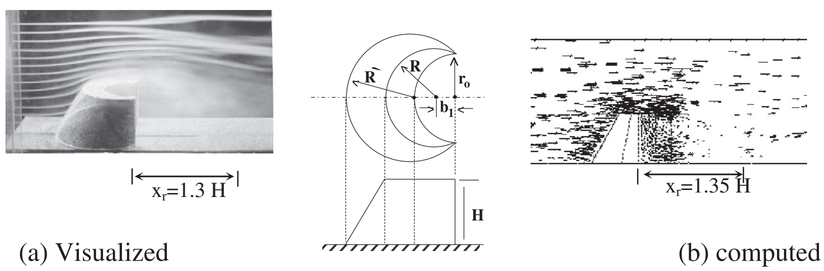

Fig. 14 Flow pattern around crescent-shaped model with slant windward side (idealized "Barchan" dune), (no fence: $H/b = 0.6$, $r_o/R = 0.9$, $b_1/b = 2.0$, $R'/R = 1.3$).

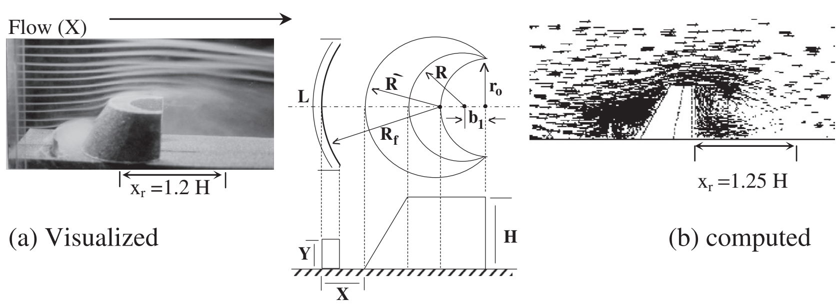

Fig. 15 Flow pattern around crescent-shaped model with slant windward side (idealized "Barchan" dune), (with fence: $H/b = 0.6$, $r_o/R = 0.9$, $b_1/b = 2.0$, $R'/R = 1.3$, $Y/H = 0.3$, $L/2R = 0.97$, $R_f/R = 1.96$, $x/H = 0.5$).

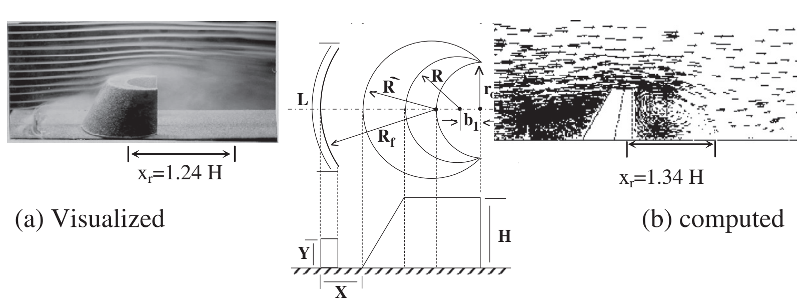

Fig. 16 Flow pattern around crescent-shaped model with slant windward side (idealized "Barchan" dune), (with fence: $H/b = 0.6$, $r_o/R = 0.9$, $b_1/b = 2.0$, $R'/R = 1.3$, $Y/H = 0.3$, $L/2R = 0.97$, $R_f/R = 2.6$, $x/H = 1.0$).

for the turbulence energy and its dissipation. These governing equations are traditionally given as "continuity", "momentum", and "energy" equations (see Ref. [2]). Solutions of these equations are subject to boundary conditions. The boundary

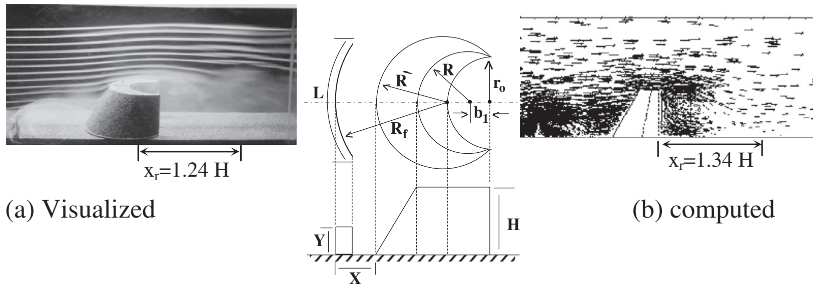

Fig. 17 Flow pattern around crescent-shaped model with slant windward side (idealized "Barchan" dune), (with fence: $H/b = 0.6$, $r_o/R = 0.9$, $b_1/b = 2.0$, $R'/R = 1.3$, $Y/H = 0.3$, $L/2R = 0.97$, $R_f/R = 3.3$, $x/H = 1.5$).

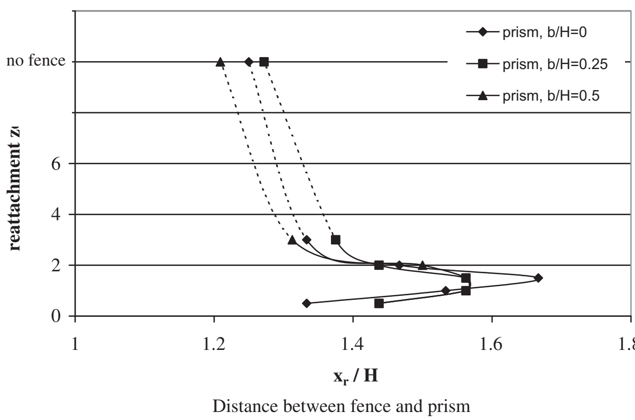

Fig. 18a Visualized position of reattachment downstream for prism model.

condition stipulating zero flow velocity at all solid surfaces (i.e. viscous fluid flow) is applied. Also, the approaching velocity profile is prescribed.

Results and discussion

Models simulating random sand formations

Fig. 3 and 4 show results obtained for a square-based triangular prism model (which may also simulate a transverse-type dune). In Fig. 3, where no fence was mounted, the flow patterns (visualized and computed) indicate a region of eddy-type flow on the leeward side with reattachment occurring approximately two model heights downstream of its base ($x_r/H \cong 2.0$). In nature this dune-sheltered zone is expected to diminish and eventually disappear as sand continues to drift from dune crest. The dune itself would ultimately disappear and the initially-sheltered zone would be covered with sand. Consequently, any structure existing in this dune-sheltered zone would be endangered. In Fig. 4, a fence whose height is approximately one third of the model height was mounted relatively away from the upstream side of model base (1.5 times model base width) shows a marked effect of the fence on the flow pattern. A region of circulatory (eddy-type) flow has appeared between the model and the fence. Also the model-sheltered zone is now shorter (approximately one model height long ($x_r/H = 1.0$)). However, such model/fence

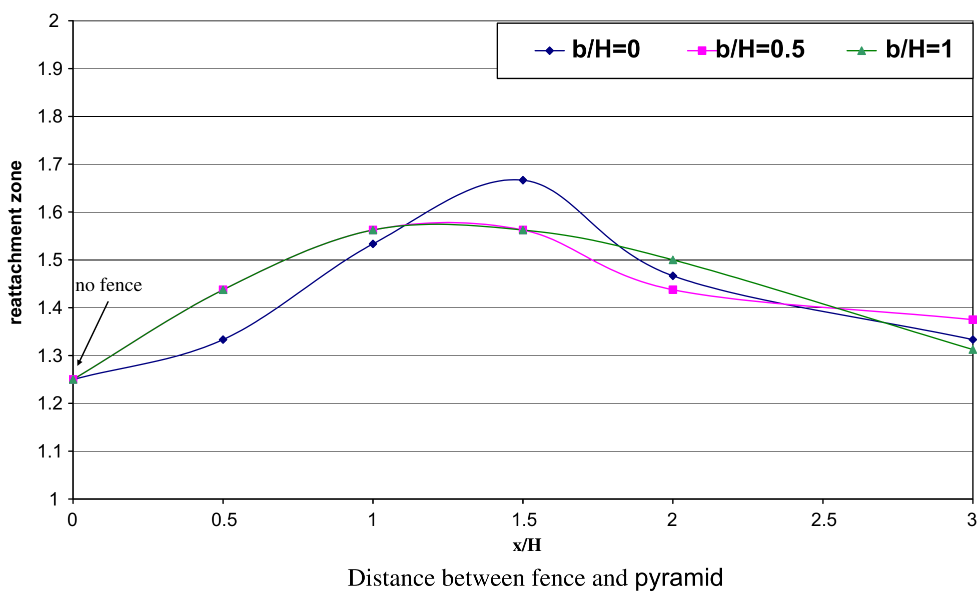

Fig. 18b Variation of position of reattachment zone with fence distance (x) for different pyramid models ($b/H = 0$, $b/H = 0.5$, and $b/H = 1$.

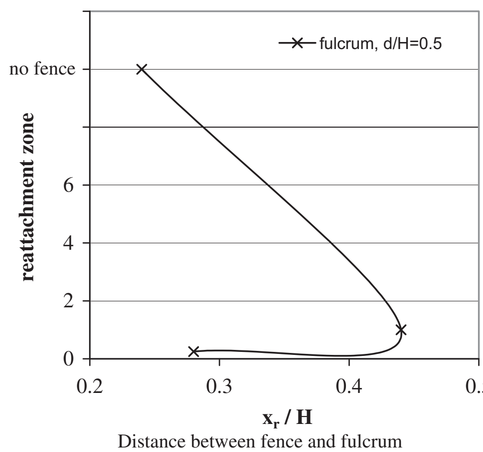

Fig. 19a Variation of position of reattachment zone with fence distance (x) for fulcrum model.

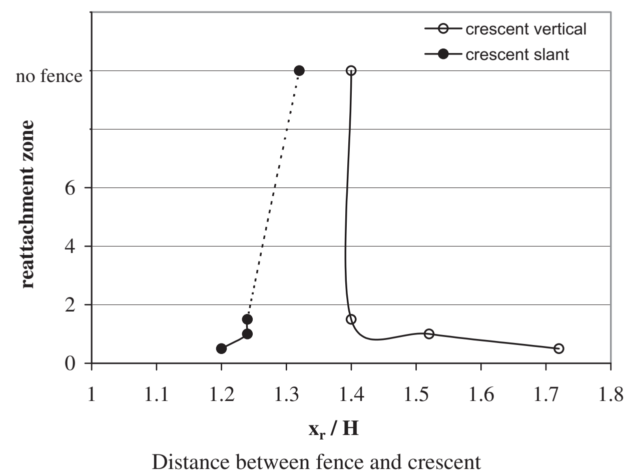

Fig. 20a Variation of the reattachment zone downstream crescent model.

arrangement in nature is expected to result in: (i) erosion of the dune windward surface by effect of severe eddies in the dune/fence inter-region (under such effect, the dune would eventually shift towards the fence and the dune sheltered zone would become longer) and (ii) reduction of sand drift rate from dune crest (less or no saltation in the dune sheltered zone). Figs. 5 and 6 show similar results for the case of square-based trapezoidal prism model where the same argument is valid here also. Figs. 7–9 show pictures of visualized as well as computationally-obtained flow patterns around a fulcrumed-cone model with and without fencing. Fig. 7b, where a fence is absent, indicates a comparatively short model-sheltered zone (not clear enough in Fig. 7a). Here, the roundness of the model appears to give a chance for the flow over its top and the flow around its sides to mix shortly behind the model. Figs. 8 and 9 compare the effect of length of a circular fence mounted at same distance from the model base line. It appears that the longer fence (Fig. 9) results in a comparatively long model-sheltered zone (farther reattachment).

Models simulating "Barchan" dunes

Figs. 10–13 show pictures of flow patterns around a "crescent"-cross-section model with vertical windward and leeward surfaces with and without fencing. It may be observed that a close fence (of given length) has a negligible effect on the flow pattern (Fig. 11). As the fence is shifted away from the model (Figs. 12 and 13) the resulting effect on the flow regime in front of and behind the model becomes observable in the sense that eddy-type flow evolves between the fence and the model in addition to a noticeably longer model-sheltered zone. In comparing this case with Fig. 10 (no fence) a larger model-sheltered area appears to have occurred together with severe

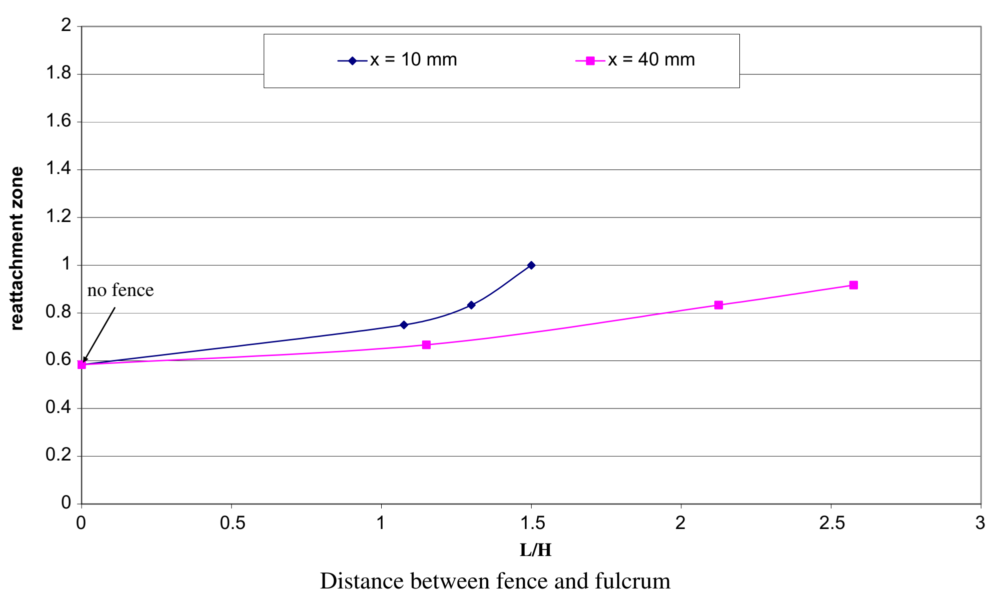

Fig. 19b Variation of the reattachment zone with fence length (L) for different fence distance (x) for different fulcrum models, (D = 40 mm, d = 20 mm, H = 40, Y = 12 mm).

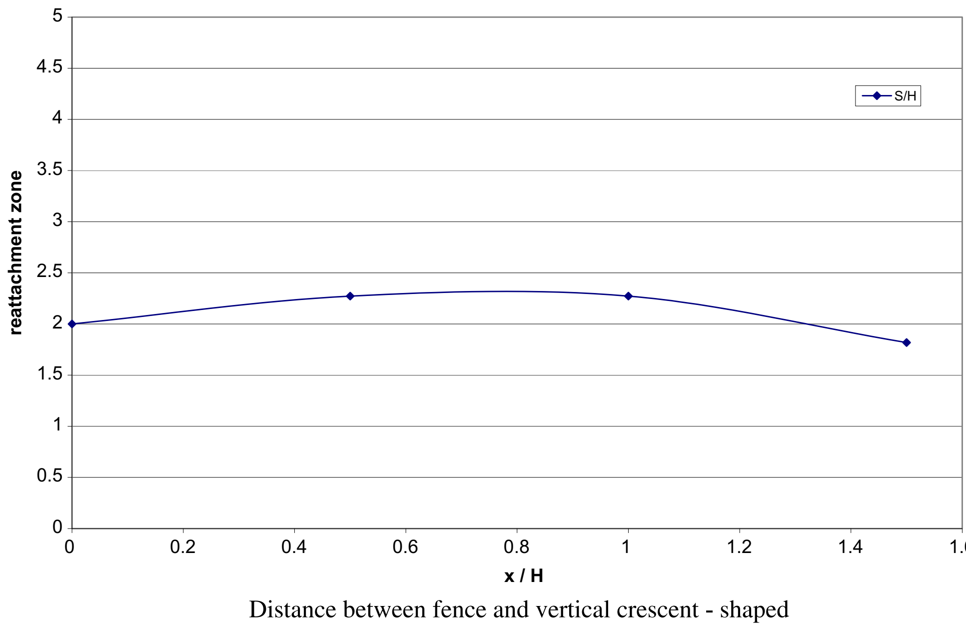

Fig. 20b Variation of reattachment distance for different fence distance (x) of the vertical crescent-shaped model (H = 40 mm, Y = 12 mm).

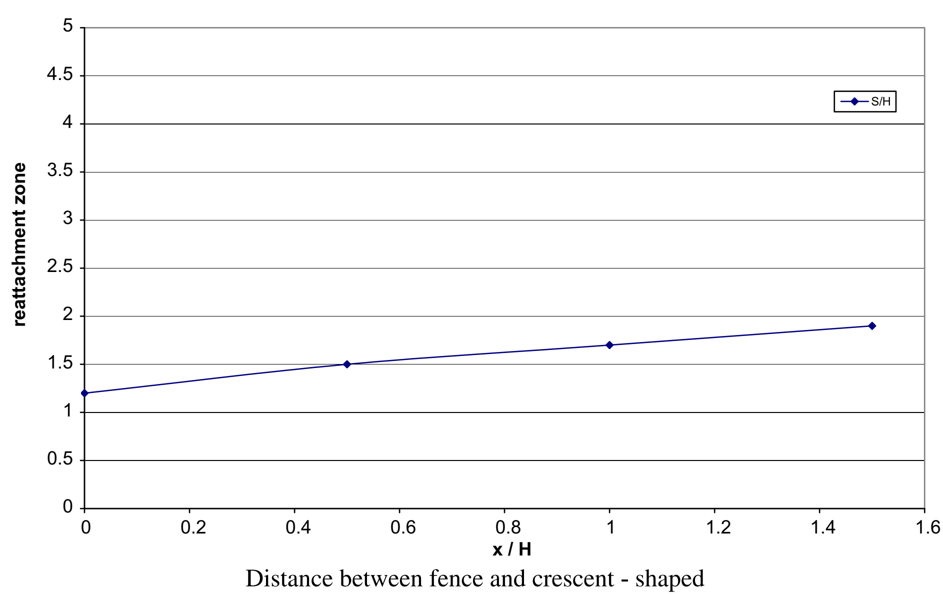

Fig. 20c Variation of reattachment distance for different fence distance (x) of the slant crescent-shaped model (H = 40 mm, Y = 12 mm).

circulatory flow in the fence/model inter-region. Fig. 14–17 give pictures corresponding to Figs. 10–13 but for a ‘‘crescent-cross-section model with slant windward surface and vertical leeward surface. This model was considered for better simulation of the real ‘‘Barchan’’ dune (where both surfaces are usually slant). The same argument given above for the case of both surfaces being vertical is still valid.

Overall effect of fencing on reattachment

Fig. 18a shows how the position of reattachment downstream of model base line is affected by the presence of the fence for the prism shape for a different ratio of x_r/H. As shown in Fig. 18b the effect on the reattachment zone as a function of the distance between the fence and the prism was established for different values of the ratio between the length of the prism top square to the dune height ($b/H = 0$, $b/H = 1$, $b/H = 2$). Fig. 19a shows the graphical relationship between the reattachment zone as a function of distance between the fence and the fulcrum model. As illustrated in Fig. 19b the effect on the reattachment zone as a function of the distance between fence and the fulcrum model was defined for different distances between fence and model. Fig. 20a shows that the crescent-shaped model with vertical side surfaces gives the farthest reattachment when a fence is mounted (nearly two model heights upstream). Fig. 20b illustrates variation of reattachment zone with a distance between fence and model in case of the vertical crescent-shaped model. Fig. 20c illustrates variation of reattachment zone with a distance between fence and model in case of slant crescent-shaped model.

Conclusions and recommendations

(i) Flow visualization and computational techniques are reliable in understanding the flow regime around humps and dunes.
(ii) Solid fencing (constructed from masonry bricks or stones) to shelter isolated sand humps and dunes is effective in alleviating dangers on nearby structures (dune shifting upwind and to less sand drift and saltation downwind).
(iii) Long fences mounted reasonably away from dune base appear more effective compared with closely-mounted ones.
(iv) If a structure (highway, factory, transmission tower, canal etc.) is to be constructed in the downwind side of a dune zone, it is recommended to start by dune fencing and give enough time for the project zone to widen and be effectively protected before starting the construction.

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